

Mapping and Monitoring Delmarva Fox Squirrel Habitat Using an Airborne LiDAR Profiler

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Ross Nelson

Code 923-Biospheric Sciences Branch
NASA/Goddard Space Flight Center, Greenbelt, Maryland 20771 USA
301-614-6632(v), 301-614-6695(f), Ross.F.Nelson@nasa.gov

Mary Ratnaswamy

Threatened and Endangered Species Program
U.S. Fish and Wildlife Service, Chesapeake Bay Field Office
177 Admiral Cochrane Drive, Annapolis, Maryland 21401
1-410-573-4541(v), 410-269-0832(f), Mary_Ratnaswamy@fws.gov

Cherry Keller

Threatened and Endangered Species Program
U.S. Fish and Wildlife Service, Chesapeake Bay Field Office
177 Admiral Cochrane Drive, Annapolis, Maryland 21401
1-410-573-4532(v), 410-269-0832(f), Cherry_Keller@fws.gov

ABSTRACT

Twenty five hundred thirty nine kilometers of airborne laser profiling and videography data were acquired over the state of Delaware during the summer of 2000. The laser ranging measurements and video from approximately one-half of that data set (1304 km) were analyzed to identify and locate forested sites that might potentially support populations of Delmarva fox squirrel (DFS, *Sciurus niger cinereus*). The DFS is an endangered species previously endemic to tall, dense, mature forests with open understories on the Eastern Shore of the Chesapeake Bay. The airborne LiDAR employed in this study can measure forest canopy height and canopy closure, but cannot measure or infer understory canopy conditions. Hence the LiDAR must be viewed as a tool to map potential, not actual, habitat. Fifty-three potentially suitable DFS sites were identified in the 1304 km of flight transect data. Each of the 53 sites met the following criteria according to the LiDAR and video record: (1) at least 120m of contiguous forest; (2) an average canopy height >20m; (3) an average canopy closure of >80%; and (4) no roofs, impervious surface (e.g., asphalt, concrete), and/or open water anywhere along the 120m length of the laser segment. Thirty-two of the 53 sites were visited on the ground and measurements taken for a DFS habitat suitability model. Seventy eight percent of the sites (25 of 32) were judged by the model to be suited to supporting a DFS population. Twenty-eight of the 32 sites visited in the field were in forest cover types (hardwood, mixedwood, conifer, wetlands) according to a land cover GIS map. Of these, 23 (82%) were suited to support DFS. The remaining 4 sites were located in nonforest cover types - agricultural or residential areas. Two of the four, or 50% were suited to the DFS. All of the LiDAR flight data, 2539 km, were analyzed to

estimate county and statewide forest area in different height/canopy closure classes. 3.3% of Delaware (17,137 ha) supports forest over 20m tall with crown closures exceeding 80%; the corresponding county percentages are Newcastle County – 6.1% (6823 ha), Kent County – 2.2% (3431 ha), and Sussex County – 2.7% (6883 ha). Newcastle is the most urbanized of the three counties, Kent and Sussex are more heavily forested and agrarian. The airborne laser measured 402, 270, 498, and 1170 contiguous patches along flight transects totaling 548.8 km, 737.5 km, 1252.2 km, and 2538.5 km in Newcastle, Kent, Sussex, and Delaware, resp. The average size of a patch of forest >20m tall with canopy closure >80% is 17.0 ha in Newcastle County, 12.7 ha in Kent, 13.8 ha in Sussex, and 14.7 ha for the state overall. The average distance between patches was 1.3 km, 2.7 km, 2.4 km, and 2.1 km in Newcastle, Kent, Sussex, and Delaware, resp. Study results indicate that: 1) systematic airborne LiDAR data can be used to screen extensive areas to locate potential DFS habitat; 2) 78% of sites meeting certain minimum length, height, and canopy closure criteria will support DFS populations, according to a habitat suitability model; 3) airborne LiDAR can be used to calculate county and state acreage estimates of potential habitat., and 4) the linear transect data can be used to calculate patch statistics. The authors suggest that the systematic county and state flight lines can be revisited at intervals to monitor changes to the areal extent of potential habitat over time.

INTRODUCTION

The Delmarva Fox Squirrel (DFS, *Sciurus niger cinereus*), an endangered species on the Delmarva Peninsula, was endemic to mature, closed canopy forest stands with open understories and plentiful mast production (Bendel and Therres 1994). Reduction in habitable area and landscape fragmentation has reduced the amount of mature forest needed to support viable subpopulations to the point where the DFS was placed on the endangered species list in 1967. Range constriction was fundamental to listing the DFS as endangered, and documentation and protection of available habitat is considered a top priority to determine if downlisting it to a "threatened" status is warranted. The need to assess and monitor DFS habitat rapidly over large areas (e.g. states and regions) has been identified in both the 1993 Delmarva fox squirrel Recovery Plan and the draft Interim Conservation Strategy for this species.

An airborne LiDAR (Light Detection And Ranging) system can be used to locate potential DFS habitat and to monitor forest area change over time. Airborne lasers (or "airborne LiDAR") may be used to remotely measure forest structure, specifically forest canopy height, height variability (Nelson et al. 1988; Nilsson 1996; Næsset 1997), percent canopy cover (Ritchie et al. 1993), and vertical vegetation structure (Blair and

Hofman 1999; Blair et al. 1999, Lefsky et al. 2002). An airborne laser profiler acquires precise ranging measurements from aircraft to targets directly beneath the aircraft along flight lines 10's or 100's of kilometers long. The distance between sequential ranging measurements is project-specific and adjustable, but typical post spacing is on the order of 0.1 - 0.5 m. The sequential ranging measurements provide a view similar to a knife slice across the terrain; when that knife slice is viewed from the side, a profile of the landscape emerges (Figure 1). The laser profiling data can be treated as a linear sample (Kaiser 1983; DeVries 1986; Andrianarivo 1993) and used to develop estimates of forest and nonforest resources. The airborne laser profiling transects can be parsed into forest and nonforest segments and, in fact, can be further parsed into segments with particular height (e.g., forests > 20m tall) and land cover (e.g., roofs, asphalt/concrete, open water) characteristics.

Airborne LIDAR profiling measurements were acquired over the entire state of Delaware during the summer of 2000 using a small, relatively inexpensive, transportable airborne laser profiling system (Nelson et al., 2003a). The year 2000 Delaware laser measurements were used to estimate county and state forest resources, e.g., merchantable volume, total aboveground dry biomass, carbon (Nelson et al. 2003b, 2004). The same data were also used to estimate impervious surface area, open water area, and were used to identify areas that might support the Delmarva fox squirrel (Nelson et al. 2003b). The first-return laser used in this study senses top-of-canopy characteristics; essentially no information is available concerning sub-canopy layers and ground cover. The DFS prefers tall, mature stands with plentiful mast and an open understory. Given that the LiDAR data can identify tall stands but contains no information on tree species (e.g., mast production) or ground cover conditions, the LiDAR must be viewed as a screening tool that can be used to identify potential habitat. Ground visits are needed to determine if the tall stands located by the laser profiler would, in fact, support viable DFS sub-populations.

An airborne LiDAR can be used to assess wildlife habitat if the quality and/or extent of the habitat is related to the vertical structure of forest or range. The overall objective of this study is to assess the utility of an inexpensive, airborne profiling LiDAR for DFS habitat measurement, mapping, and monitoring. The study has a number of

specific sub objectives: (1) Determine, by field visit, the percentage of these LIDAR-detected sites that actually provide habitat suitable for the Delmarva fox squirrel. Once this proportion (i.e., the ratio of tall, dense stands actually suitable for the DFS relative to the number of tall, dense stands identified by the airborne laser) is known, then regional acreage estimates of DFS habitat loss or gain can be estimated quickly by analyzing laser data acquisitions at time 0, time 1, time 2, and so on. (2) Estimate the regional extent of potential DFS habitat, by county, for the state of Delaware. (3) Calculate landscape-level patch statistics, by county, for the state. With habitat loss, development, timber harvest, and long term sea level rise considered to be primary threats to DFS recovery, this monitoring technique has the potential to serve as a quantitative, rigorous, and time-efficient management tool.

BACKGROUND

An airborne laser measures vertical structure at very fine (sub-meter) scales, and decades of research have gone into relating these measurements to forest structure (e.g., height, height variability or roughness, canopy closure, empirical height distributions) and to mensurational items of interest to forest managers (e.g., basal area, merchantable volume, biomass) and environmental managers (e.g., carbon, impervious surface area, area under roof, open-water area, reef mapping, coral bleaching). Operationally, these natural resource applications are secondary to a much larger field, topographic mapping, where lasers are commonly employed to generate detailed topographic maps for anything from highway siting to hydroelectric planning/inundation mapping to beach erosion. Airborne lidars are used to make 3-D images of objects such as buildings, towns, and are used to monitor high-voltage power lines for sag and the right-of-ways for vegetation growth. An airborne scanning LiDAR system was used to measure the amount of debris that had to be handled after the collapse of the World Trade Centers (use any internet search engine and enter - lidar WTC). Hundreds of commercial vendors exist in the US alone, and the technology employed to make these airborne ranging measurements is mature.

Vertical forest structure is related to biodiversity and habitat. "In general, the more vertically diverse a forest is the more diverse will be its biota..." (Brokaw and Lent

1999). Jansson and Andrén (2003), working in a managed boreal forest in Sweden, found that the number of bird species increased as the proportion of older mixed forest increased and as tree height increased, but species numbers fell as the fragmentation index increased. Beier and Drennan (1997), studying Northern Goshawks, found that these birds selected foraging sites based on forest structure rather than on prey abundance. These raptors, adapted for hunting in relatively dense, mature forests, hunted in forest stands with higher canopy closure (>40%), higher tree densities, and taller trees, even if these sites had lower prey abundance than found in more open stands. Lindenmayer et al. (2000) calls for the development of structure-based indicators of forests at the stand and landscape level, ones which might be related to the presence/absence of indicator species or which might be used to measure habitat quality and/or biodiversity directly. Airborne lasers measure stand and landscape level structure; what remains to be done is to relate these measures to faunal species and habitat.

Hinsley et al. (2002) and Hill et al. (2003) have employed an airborne laser system to assess bird habitat. They used an airborne laser scanning system to map forest structure across a 157 ha deciduous woodland in the eastern United Kingdom. The researchers relate laser-based forest canopy heights to chick mass (i.e., nestling weight), a surrogate for breeding success, which, in turn, is a function of "territory quality". They found that, for one species, chick mass increased with increasing forest canopy height, and for a second species, chick mass decreased. Hill et al. (2003) relate these findings to differences in species foraging preferences and extant weather conditions. Hill et al. (2003) concludes that airborne laser scanning data can be used to predict habitat quality and to map species distributions as a function of habitat structure.

Nelson et al. (2003b) mapped and estimated the areal extent of Delmarva fox squirrel habitat using an airborne profiling LiDAR flown over Delaware. The airborne profiler was used to locate, delineate, and measure tall, dense forest stands across the State. 1106 potential DFS sites were located, and areal estimates were derived by evaluating flight data acquired along systematic flight lines spaced 4 km apart. The study demonstrated the utility of an airborne laser profiler for mapping and measuring

potential DFS habitat. The current study takes the 2003 results a few steps further by 1) improving variance estimates, 2) relating airborne LiDAR measurements to DFS habitat suitability assessed using coincident ground measurements and a habitat suitability model, 3) estimating the areal extent of DFS habitat, by county and state, based on 2539 km of flight data, and 4) reporting airborne laser-based, landscape-level patch statistics.

PROCEDURE

Selecting Candidate Field Sites Using Airborne LiDAR Data

1304 km of laser ranging measurements collected along systematically arrayed N-S flight lines in 2000 were processed to identify tall, mature forest stands that might support the DFS. The laser flight lines were registered to a digital map of Delaware (University of Delaware GIS - <http://www.udel.edu/FREC/spatlab/>). with eight land cover classes – hardwood, mixedwood, conifer, wetlands, agriculture, residential, urban/barren, and open water. The video records along all 1304 km of flight data were reviewed to identify linear segments where the laser measurements crossed roofs, asphalt, concrete, or open water. Linear segments were identified that were at least 30m long, 20m tall, with a minimum canopy cover of 80%, and that did not intercept any sort of manmade surface or open water. 1106 such segments were located statewide (see Nelson et al. 2003b, Figure 1) These tall segments were then screened to identify all areas where four or more 30m segments were conjoined, making a "super-segment" at least 120 m long. Fifty three super-segments greater than or equal to 120 m were located; 31 of these were ≥ 150 m; 19 were ≥ 180 m; and 14 were ≥ 210 m. Only two super-segments ≥ 300 m long were found; the longest was 420 m. From this list, 35 candidate field sites were selected based on cover type (from the GIS) and length. The selection of 120 m as a minimum length was a pragmatic decision made based on two competing considerations: (1) sample size, i.e., the number of candidate laser sites available to be sampled in the field, and (2) the length of the ground sample needed to evaluate habitat suitability. As described in the next section, segments at least 200m long were preferred because field procedures required the use of a 200m ground transect. The 120 m laser interception length should not be interpreted as any sort of

minimum criterion associated with site suitability; rather it is driven by ground sampling constraints. Also, sites were selected to try to acquire samples in each of seven, GIS-defined cover types; no sites were selected in the open water cover class. Given these selection criteria, 10 sites each were selected in hardwood, mixedwood, and wetlands, one in conifer, one in agriculture, and three in residential areas. The conifer, agriculture, and residential sites were the only ones identified statewide that met the prescribed minimums – 120 m long, 20 m tall, 80% crown closure.

Ground Sampling to Assess DFS Site Suitability

Dueser et al (1988) developed a Delmarva fox squirrel habitat suitability model based on field measurements made by Taylor (1976). Taylor characterized 54 sites on Maryland's Eastern Shore; 36 sites were occupied by the DFS, 18 sites did not support DFS populations. Taylor used a 4m x 200m "belt transect" to quantitatively describe habitat characteristics. Transect measurements include tree diameter, tree species, understory density, and overstory canopy closure. Dueser et al. (1988) developed a two-group discriminant function to predict DFS presence/absence based on the 200m transect measurements. They found that sites which supported these endangered squirrels "had a greater percentage of trees >30cm dbh, lower percentage shrub-ground cover, and slightly lower understory vegetation density" (Dueser et al 1988, pg. 416). Forest species composition was not a significant factor, nor was basal area. Using a jackknifing procedure, Dueser found that the discriminant function correctly classified "present", i.e., occupied sites, 79% of the time; "absent", unoccupied sites were correctly classified 48% of the time. Dueser's model is the only existing quantitative model specifically designed to assess DFS site suitability. Efforts are currently underway at Virginia Tech to refine this model and to integrate airborne laser canopy measurements into the model.

The airborne laser records ranging data which may be used to characterize forest structure, and it also records GPS data related to aircraft position, direction of flight, speed, and altitude. The 35 sample sites were located in the field using the aircraft GPS locations. Three of the 35 sites were not measured - two because the landowners denied permission to access their land, one because a significant proportion of the trees along the ground transect were blown down after the laser

overflight but prior to the field sample. On the ground, a handheld GPS unit was used to locate the starting point of a ground sample, and then a 200m compass line was chained along the flight azimuth. Given the accuracy of the aircraft differential position (~5-10m horizontal) and under-canopy, differential GPS errors incurred when locating the sample starting point, the authors estimate that the ground-located flight path was within 10-20m of the actual flight path flown. As per Taylor (1976) and Dueser et al. (1988), a 4 meter wide belt was established along the 200m segment of the flight and forest measurements were taken to supply the Dueser DFS habitat suitability model.

Occasionally, since the minimum contiguous forest "super-segment" considered was 120m, situations arose where the 200m ground transect exited the forest stand mapped using the airborne lidar. In these situations, the transect was either 1) extended from the starting point in a direction opposite the original field azimuth along the laser flight line, or 2) turned orthogonally or acutely, so that the remainder of the sample transect stayed within the bounds of the same forest stand.

Estimating Area of Potential DFS Habitat, by County and State

2539 km of airborne laser ranging data acquired along 28 N-S flight lines were processed to characterize forest height and canopy closure, by county and for the state. The processing involved parsing each flight line into segments ≤ 40 m and calculating the average height and closure of the vegetation canopy in each segment. The length of any segment ≥ 30 m long was summed, by flight line, into one of 4 height/canopy closure classes – (1) segments >20 m tall with canopy closure between 80-90%, (2) segments >20 m tall with canopy closure $> 90\%$, (3) segments > 25 m tall with canopy closure between 80-90%, and (4) segments >25 m tall with canopy closure $>90\%$ (Figure 2). Line Intercept Sampling techniques are used to convert the linear measurements to area estimates (Kaiser 1983; DeVries 1986). The percentage of a particular flight line in a given height/canopy closure class, multiplied by the area of the county, provides one estimate of area in that forest class. Each flight line provides an independent estimate of forest area in any given height/canopy closure class. The 28 flight lines are used to calculate a weighted mean and variance estimate for each class, with the weights corresponding to flight line lengths.

Let l_{ij} = length (m) of intersection of a particular height/canopy closure class in

county i , flight line j (minimum length tallied – 30 m),

L_{ij} = total length (m) of flight line j in county i ,

L_i = total length (m) of all flight lines in county i ,

a_i = area of county i (ha), from ancillary information, e.g., GIS, state statistics,

n_i = number of flight lines that transect county i ,

q_{ij} = total area (ha) of potential squirrel habitat in county i , as estimated by flight line j ,

q_i = total area (ha) of potential squirrel habitat in county i .

Then, the **total area** in a particular height – canopy closure class is

$$\hat{q}_i = \sum_{j=1}^{n_i} (w_{ij})(\hat{q}_{ij}) \quad (\text{eqn. 1})$$

where $\hat{q}_{ij} = \left(\frac{L_{ij}}{L_i} \right) (a_i)$, $w_{ij} = \frac{L_{ij}}{L_i}$, and $\sum_{j=1}^{n_i} w_{ij} = 1.0$.

The **variance** of that total area estimate is

$$\text{var}(\hat{q}_i) = \frac{\sum_{j=1}^{n_i} w_{ij} (\hat{q}_{ij} - \hat{q}_i)^2}{n_i - 1} \quad (\text{eqn. 2})$$

This weighted variance treats systematically located flight lines as a random sample. This variance is most likely conservative, i.e., overestimated, since (1) most forest variables are spatially autocorrelated (e.g., large trees are more likely to be found near other large trees), and (2) a positive correlation between pairs of observations, e.g., flight lines, in the same systematic sample will reduce the variance of the systematic sample (Cochran 1977, pgs 208-209, Scheaffer et al. 1990, pg. 210). One example of the increase in precision afforded by systematically estimating the areal extent of specific land cover types can be found in Osborne et al. (1942), where he reports random sampling standard deviations 2-5 times larger than systematic sampling standard deviations. J. Heikkinen (2004, Finnish Forest Research Institute, personal communication) points out that the upward bias that results from treating a systematic sample as a random sample can be mitigated by differencing spatially adjacent

observations in a systematic sample rather than differencing observations with the mean, but this still leads to conservative, upwardly biased variance estimates. He cites work by Lindeberg (1924, 1926), who provides formulas for mitigating this bias:

$$\text{var}(\hat{q}_i) = \frac{n_i}{2(n_i - 1)} \sum_{j=1}^{n_i-1} \left(\frac{L_{ij} + L_{i,j+1}}{2L_i} \right)^2 (\hat{q}_{ij} - \hat{q}_{i,j+1})^2 \quad (\text{eqn. 3})$$

$$= \frac{n_i}{8(n_i - 1)} \sum_{j=1}^{n_i-1} (w_{ij} + w_{i,j+1}) (\hat{q}_{ij} - \hat{q}_{i,j+1})^2$$

The more conservative variance formula, equation 2, is used to calculate the standard errors reported in the Results section.

Calculating Patch Statistics

An airborne profiling LiDAR provides distance measurements across and between forest patches. If distances across forest patches with specific height and canopy closure characteristics (e.g., >20m tall, >80% canopy closure) are recorded, and if the number of contiguous patch crossings are recorded, then average patch size and the average distance between patches can be calculated.

Let l_i = the length (m) of intersection of forests >20m tall with canopy closure >80 in county i , for all flight lines traversing the county, and

n_p = number of contiguous patches of forest >20m tall, >80% closure intercepted for all flight lines traversing county i .

Then the average patch size in county i , p_i , in hectares, and the average distance between patches in county i , d_i , in meters are calculated, based on laser intercept distances and counts, as follows:

$$p_i = \frac{\left(\frac{l_i}{L_i} \right) (a_i)}{n_p} \quad (\text{eqn. 5}) \quad \text{and} \quad d_i = \frac{L_i - l_i}{n_p} \quad (\text{eqn. 6})$$

Bender et al. (2003) and Tischendorf et al. (2003) have pointed out that distance-based metrics such as p_i and d_i are not as informative as area-based measures, e.g., buffer-related area estimates, with respect to characterizing patch isolation to predict, for instance, immigration. These laser-based landscape-scale metrics are provided because (1) they're readily calculated using airborne profiling laser data; and (2) they provide, at a reconnaissance level, a quantitative measure of habitat quality, one that might be used to monitor changes to regional habitat over time.

RESULTS

Mapping Candidate Sites

Thirty-five of 53 potential DFS habitat sites were visited in the field. Of these 35 sites, 3 were not measured. Two private landowners denied permission to access their land because of economic concerns associated with the presence, potential or real, of an endangered species on their property. One site was visited but not measured because Hurricane Isabel had blown down significant portions of the forest tract in the autumn of 2003. Thirty-two ground transects, each 200m long, were established in the field in order to acquire the ground measurements needed to run the DFS habitat model. The results are reported in Table 1. Of the 32 sites visited, 25 sites, or 78.1%, were judged by the Dueser model as capable of supporting the Delmarva fox squirrel. Twenty-eight of the 32 sites were in forest cover types (hardwood, mixedwood, conifer, wetlands) according to the digital land cover map. Of these, 23 (82%) were suited to support DFS. The remaining 4 sites were located in nonforest cover types - agricultural or residential areas. Two of the four, or 50% were suited to the DFS. This work suggests that over three-quarters of the Delaware forests >20m tall (average canopy height, all pulses) with canopy closures exceeding 80%, and linear forest crossing distances greater than 120m as measured using an airborne laser altimeter, might support DFS populations.

Not all sites are equivalent. The 32 site scores are illustrated in Figure 3, along with two discriminant centroids which Dueser uses to quantitatively describe "absent" sites - a discriminant score closest to -1.188 - and "occupied" sites - a discriminant

score closest to 0.324. The midpoint of these two centroids, -0.432, marks the dividing line between "presence" and "absence".

All of the 32 sites visited in the field supported large trees and dense canopies. 78% of these, according to the Deuser et al. (1988) model, would support DFS populations. However, these sites span the range in terms of habitat suitability. An airborne laser can be used to map locations of potential sites; ground visits must be made to each candidate site to determine presence of the DFS or to determine site suitability for DFS reintroduction. An airborne laser, then, should be viewed as a screening tool; a remote sensing instrument that can be used to quickly identify and map specific sites which can then be visited on the ground. An analyst cannot rely solely on first-return laser ranging data and videography to assess habitat suitability.

Areal Estimates of Potential Habitat

A systematic sample of airborne laser profiling transects were analyzed to estimate forest area in various height-canopy closure classes. Using Line Intercept Sampling techniques, percentages of flight line in different height-canopy closure classes can be converted to area estimates using simple ratios. County and statewide estimates are calculated by weighting individual flight line estimates. These areal estimates of Delaware forest cover are reported in Figure 4, by county and for the state.

As noted in the section directly above, not all of the forest area in the taller, denser forest classes would provide decent habitat for the DFS. However, such graphs can be used to monitor potential habitat over time, keeping in mind that a certain percentage of the taller, dense stands provide acceptable habitat. If tall, dense forest is decimated over time in a particular county or state, the wildlife biologists, though they will not know which particular DFS populations are at risk, will know that all populations, in general, in that county or state are under pressure and at risk.

Figure 4 provides some estimate of sampling sensitivity. The statistics reported in Figure 4 are based on flight lines spaced 2 kilometers apart, a sampling intensity of approximately 0.5 km of flight line per square kilometer of study area. In Newcastle County, for instance, a loss of 826 ha [or 19%, i.e., $(469 \text{ ha})(t_{0.05, df=14})$, where $t = 1.761$ and the degrees of freedom are determined by the number of flight lines] would have to be reported in a subsequent remeasurement period to conclude that the area of the 20-

25m, 90%+ height-canopy closure class had decreased significantly. In Delaware, approximately 436 ha [or 16%, i.e., (256 ha)($t_{0.05, df=27}$), where $t=1.703$] of forest >25m tall, >90% closure would have to be lost from the 2760 ha in that height/closure class in order to conclude, at the 95% level of confidence, that the loss was statistically significant. These one-sided t-calculations are made assuming that 1) the standard errors of estimate associated with the remeasurement are similar to the current year's errors, and 2) the wildlife manager is only interested in tracking and testing for significant habitat loss. A two-sided t-test would have to be employed to test for effects of deforestation and afforestation. Sensitivities can be increased by increasing the number of randomly or systematically placed flight lines. The standard errors reported in Figure 4 are, in all likelihood, conservative, i.e., overestimated, since the systematically allocated flight lines were treated as a random sample. Equivalence testing may also be employed to discern biologically or ecologically important thresholds (Parkhurst 2001; Blair and Cole 2002; Dixon 2003).

Patch Statistics

Average patch size and distance between patches of forest >20m tall and >80% canopy closure were calculated using airborne laser interception lengths and intercept counts. The average patch sizes of tall, dense forest are 17.0 ha in Newcastle County, 12.7 ha in Kent County, 13.8 ha in Sussex County, and 14.7 ha statewide. The average, linear distances between these tall, dense stands are, for Newcastle, Kent, Sussex, and Delaware, 1.3 km, 2.7 km, 2.4 km, and 2.1 km, respectively.

These averages are somewhat misleading given that these forests tend to occur in clusters, i.e., they tend to be spatially autocorrelated, a phenomenon that can be visualized by studying Figure 2 closely. Tall forest tends to grow close to tall forest. Also, not reported or considered in these numbers are forests of lesser stature that may serve as suitable habitat and/or as potential immigration/emigration paths between suitable habitat. The patch statistics consider only big wood, ignore all LiDAR crossings less than 30m long (so that many patches of tall trees which actually exist are transparent or quantitatively nonexistent in this analysis), and ignore all forests less than 20m tall. Nonetheless, these number provide a preliminary glimpse of the status of DFS

habitat in each county, and periodic airborne LiDAR acquisitions may be used to note changes in these patch statistics over time

CONCLUSIONS

Airborne lidar is a masking tool; it can be used to locate and delineate tall, closed-canopy forest stands that might support DFS populations, and it can likewise be used to rule out areas where trees are too small or too open to support DFS populations. The small, inexpensive, first-return LiDAR profiling system employed in this study provides no information concerning understory characteristics. Given that an open understory is one precondition for the presence of the DFS, ground visits must be conducted to make a final judgment concerning the acceptability of a particular location flagged by the laser.

All 32 sites characterized by the laser as supporting tall, dense forest - average heights greater than 20 m, canopy closures greater than 80%, and linear intercepts greater than 120 m long - did, in fact support large trees with closed canopies. Of these, 78% provide habitat suited to Delmarva fox squirrels. The Dueser et al. (1988) DFS habitat model evaluated pine-hardwood composition, dbh size class distribution, and understory density to assess suitability, and on 22% of the sites, one or more of these factors adversely affected squirrel habitat.

Airborne lidar profiling data in conjunction with Line Intercept Sampling techniques can be used to estimate the areal extent of different forest height - canopy closure classes. These same data can be used to calculate patch statistics, by county and for the state. Over time, such statistical summaries can be used to monitor habitat changes at the county, state, or regional level. The same flight transects can be flown periodically, e.g., once every 5 years, to assess the status of potential DFS habitat. The sensitivity of the remeasurement will depend on the number of flight lines flown and the line-to-line variability, with longer flight transects mitigating this variation. Twenty-eight flight lines were flown over Delaware in 2000, each line systematically transiting the state N-S. At this sampling intensity, coefficients of variation (standard error divided by the mean) were approximately 5-15% at the state level and approximately 10-30% at

the county level, with much larger CVs registered in rarely found height/canopy closure classes (e.g., 20-25m tall, 80-90% canopy closure).

Airborne LiDAR profilers measure tree heights, and these linear transect measurements are used to estimate the areal extent of height/canopy closure classes in each of the three counties in Delaware. In this study, realizing that the DFS inhabited tall, dense forest stands with little understory, we chose to look at forests >20m tall with canopy closures exceeding 80%. We do not suggest that 20m and/or 80% should be taken lower bounds for DFS habitat, we use these numbers only to quantitatively define our forest population of interest. It was a place to start. Subsequent studies may wish to investigate percentage of suitable habitat in dense forests 10-15m tall, or 15-20m tall.

With respect to the DFS, an airborne LiDAR system should be viewed as a screening tool, one that may be used to quickly measure forests along 100's or 1000's of kilometers of flight transect quickly. Using LIS techniques, the forest height measurements made by the LiDAR system can be converted to areal estimates of potential, not actual, habitat. The LiDAR system can point researchers to particular sites to see if the DFS is present, or to see if an area is suitable for reintroduction. The LiDAR ranging data can also be used to quantitatively describe the forests of a county, state, or region. These areas can be revisited periodically, i.e., the same flight lines can be re-flown at time zero, time1, time 2, etc., to assess habitat gain/loss and landscape-level measures of habitat quality.

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Table 1. Results from the sample of 35 - 200 meter field transects in Delaware. Field measurements served as input into the Dueser et al. (1988) Delmarva fox squirrel habitat suitability model.

<u>Cover Type</u>	<u>potential sites</u>	<u># of sites selected</u>	<u># of sites sampled</u>	<u># sites occupied</u>	<u>% sites occupied</u>
hardwood	20	10	9 *	7	77.8
mixedwood	12	10	8 **	6	75.0
conifer	1	1	1	1	100.0
wetlands	16	10	10	9	90.0
agriculture	1	1	1	0	0.0
residential	3	3	3	2	66.7
urban/barren	0	0	0	0	na
<u>open water</u>	<u>na</u>	<u>na</u>	<u>na</u>	<u>na</u>	<u>na</u>
total	53	35	32	25	78.1

* one site - blow down, Hurricane Isabel

** two sites - landowner permission denied

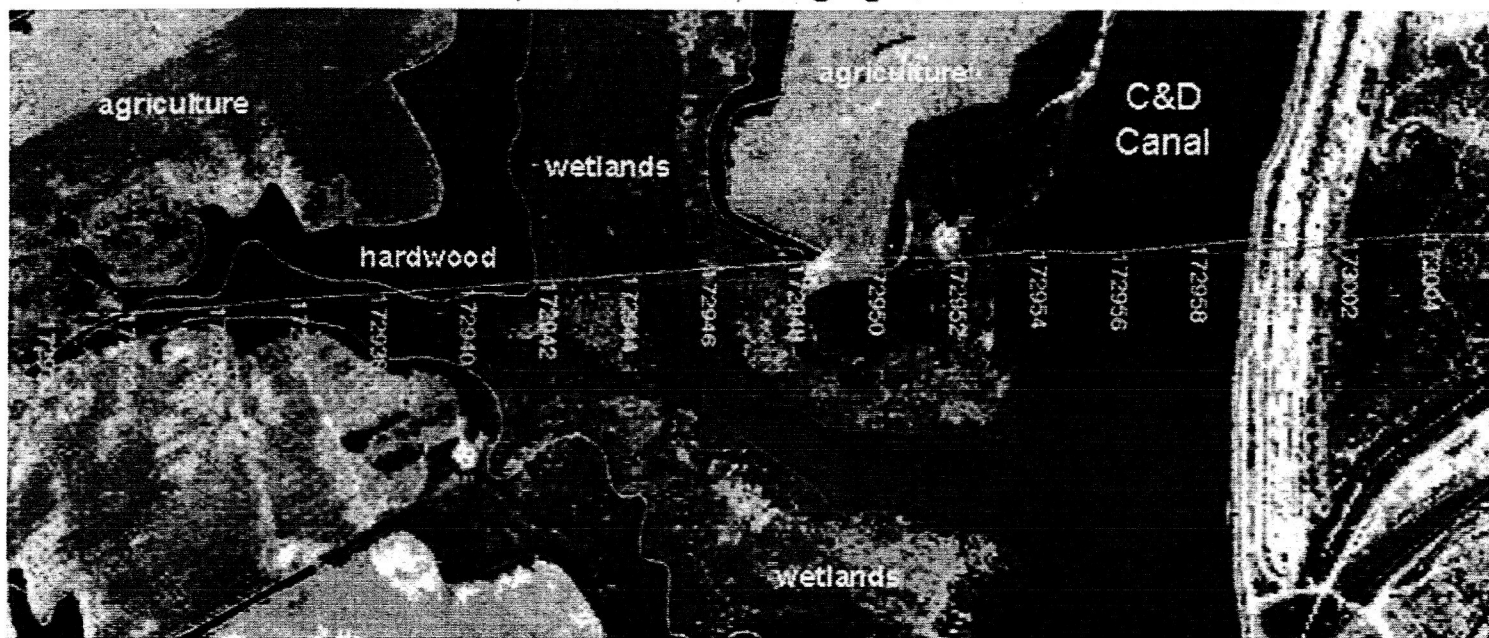
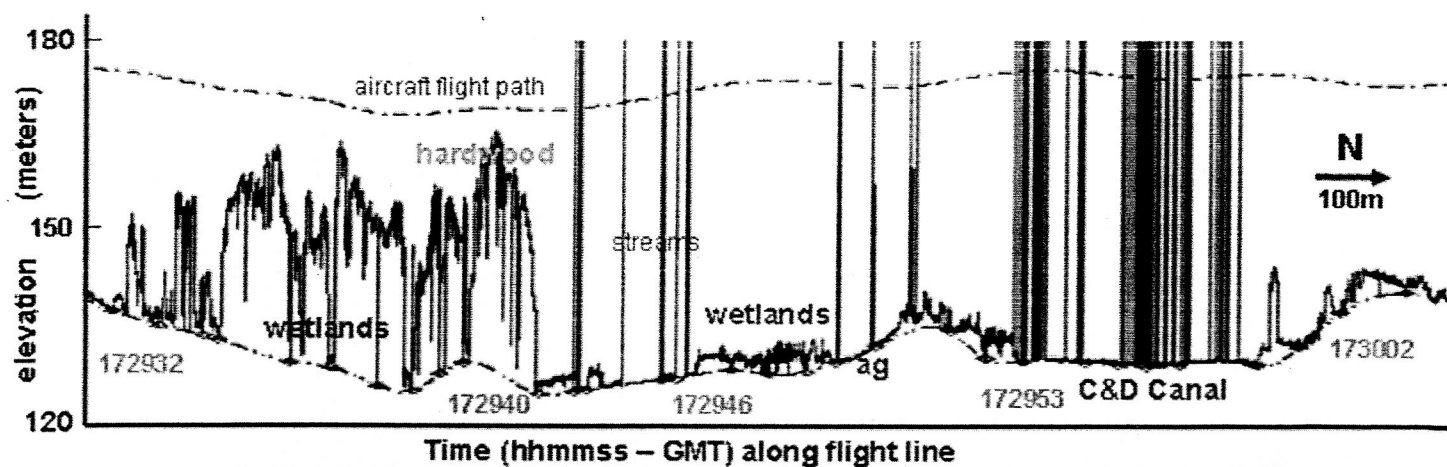


Figure 1. A 1.6 kilometer section of airborne laser flight line acquired over northeastern Delaware just west of Delaware City. The top graph is the airborne LiDAR profile corresponding to the 1992 color infrared airphoto beneath the profile. The yellow numbers on the CIR photo are GMT times associated with the laser aircraft overflight. Corresponding times are listed in red on the profile. The tall, flat-topped returns noted on the LiDAR profile represent individual laser shots where the return strength of the reflected laser pulse equaled zero. The laser transmits pulses in the near infrared (0.905 μm), and water tends to absorb these near-infrared pulses.

in color

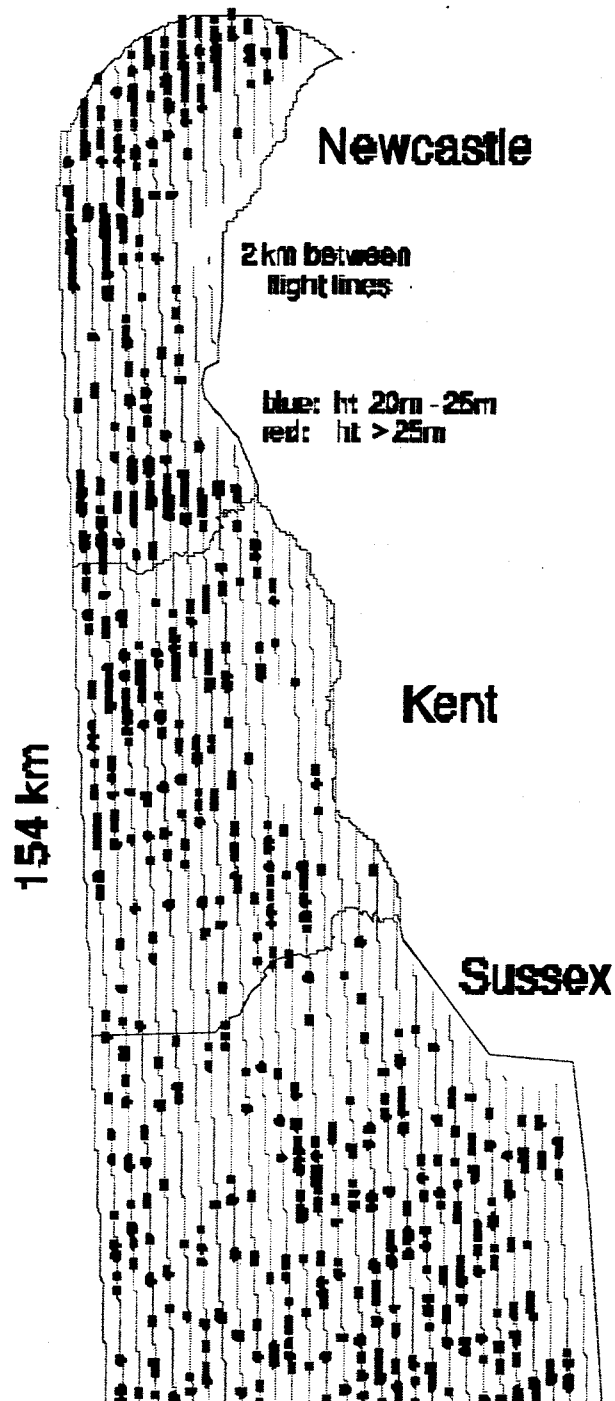




Figure 2. Laser flight lines flown over Delaware, summer 2000. 2539 km of linear airborne laser profiles were collected and analyzed. The blue and red points along the flight lines identify mature stands that are at least 30m in length, with canopy closures exceeding 80%, and which might support Delmarva fox squirrel sub-populations. The 1763 blue points mark stands with average canopy heights of 20m to 25m; the 344 red points mark stands >25m tall.

in color

-  sites on which the Delmarva fox squirrel is expected to be present; suitability score > -0.432
-  sites on which the Delmarva fox squirrel is expected to be absent; suitability score < -0.432

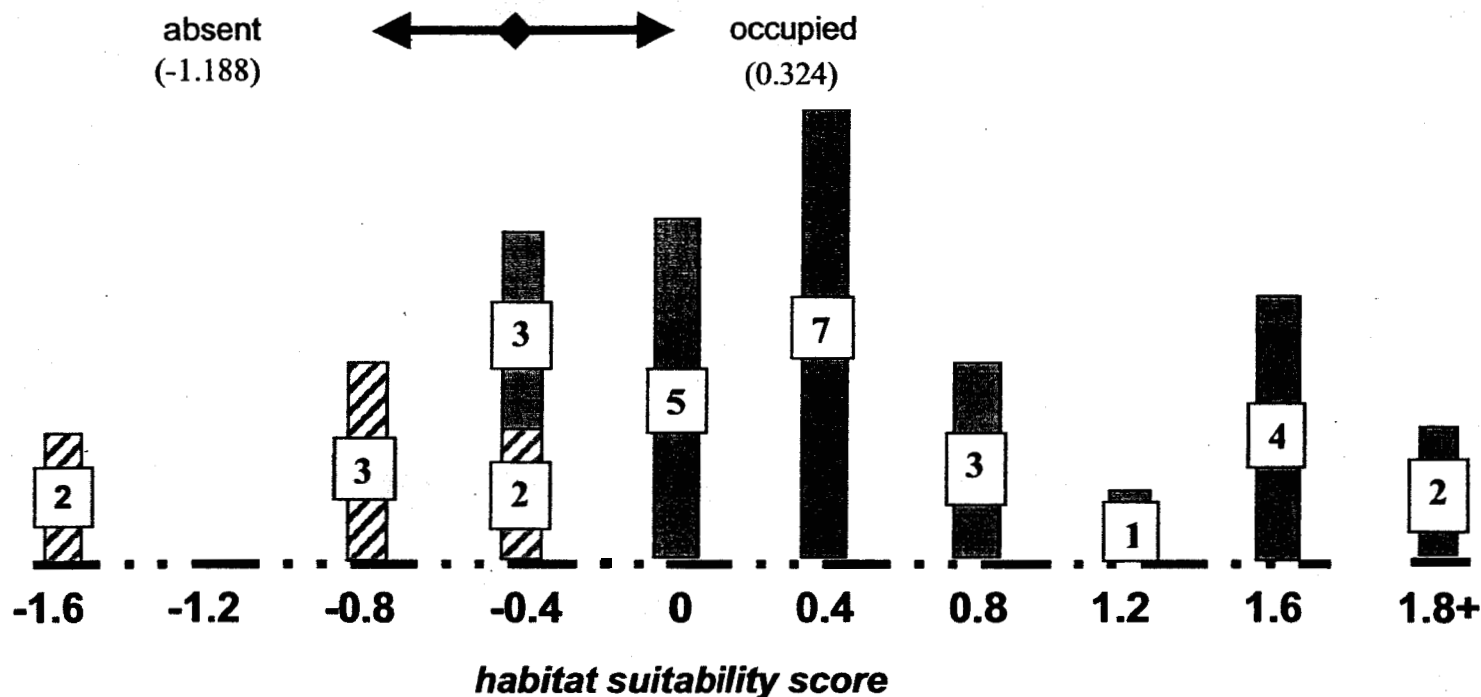


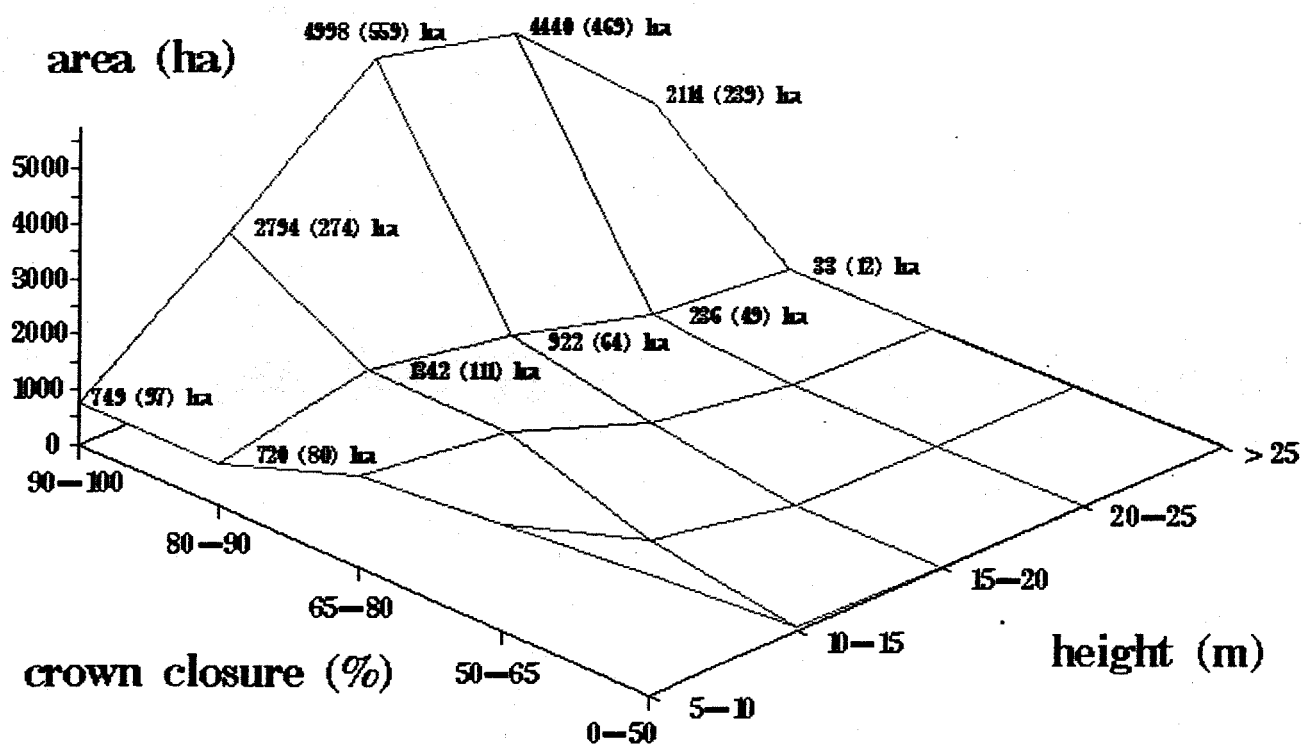
Figure 3. Distribution of Dueser habitat suitability model scores for 32 sites with average canopy heights >20m, canopy closures>80%, and linear intercept lengths > 120 m. Numbers in the square boxes report number of sites with a score within ± 0.2 of the midpoint. The lowest recorded score is -1.59, the two highest scores are 1.85 and 3.29. 0.324 is the centroid for "occupied" sites; -1.188 is the centroid for the "absent" sites.

4.A.

Newcastle County Height—Closure Areas

County Area: 112412 ha

15 flight lines, 548.8 km



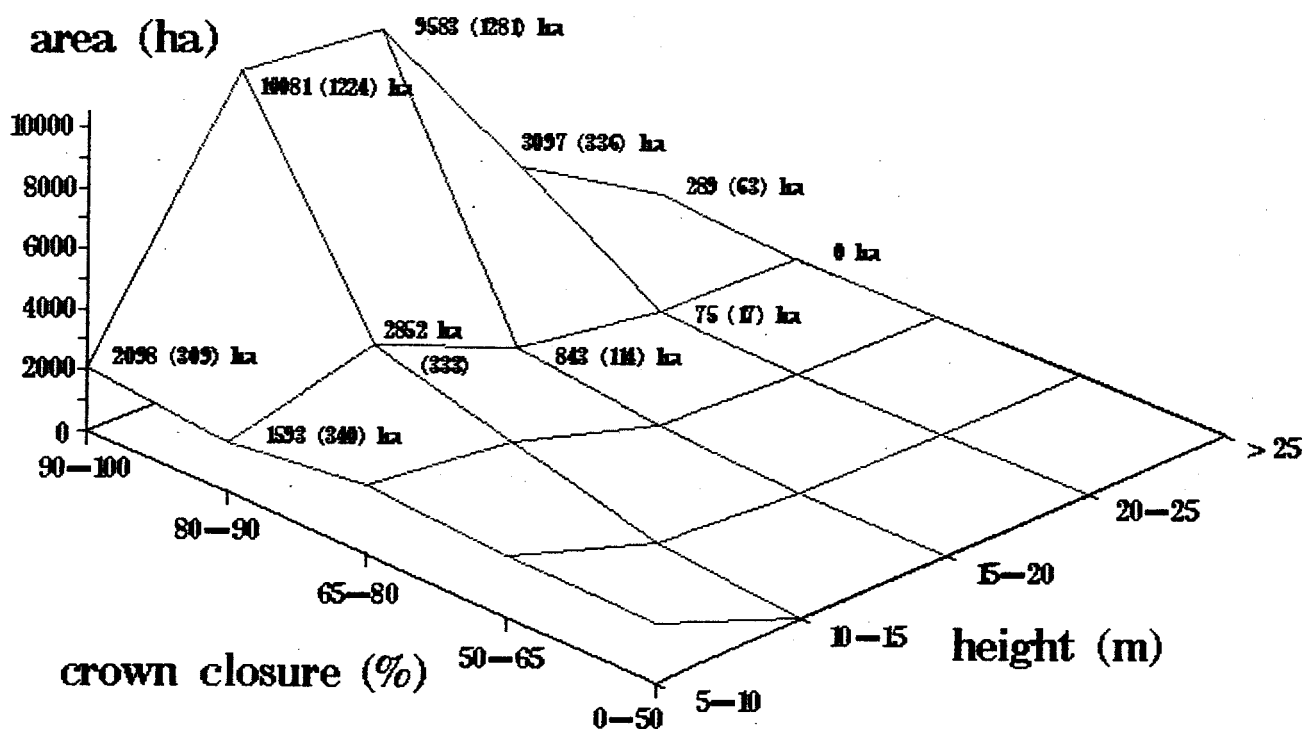
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4.B.

Kent County Height-Closure Areas

County Area: 154234 ha

E flight lines, 737.5 km



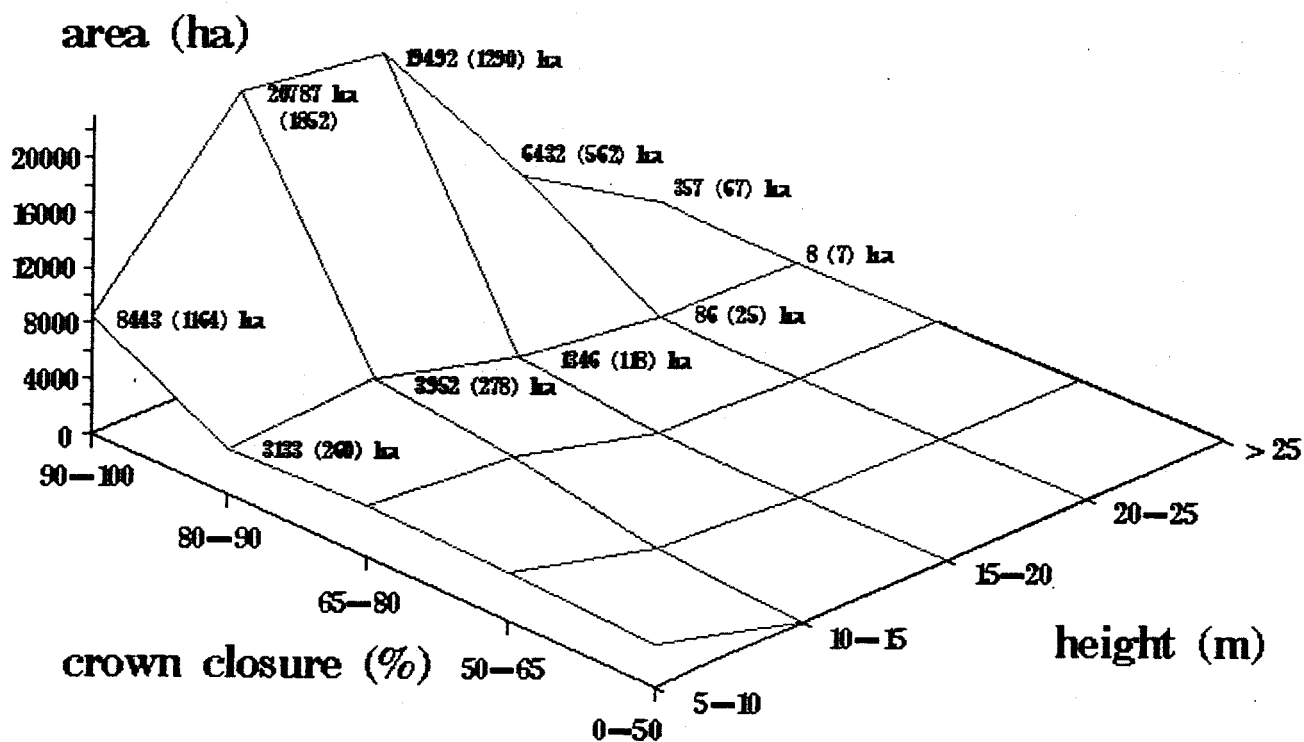
in color

4.C.

Sussex County Height-Closure Areas

County Area: 253896 ha

28 flight lines, 1252.2 km



in color

4.D.

Delaware Height-Closure Areas

County Area: 520543 ha

28 flight lines, 2838.5 km

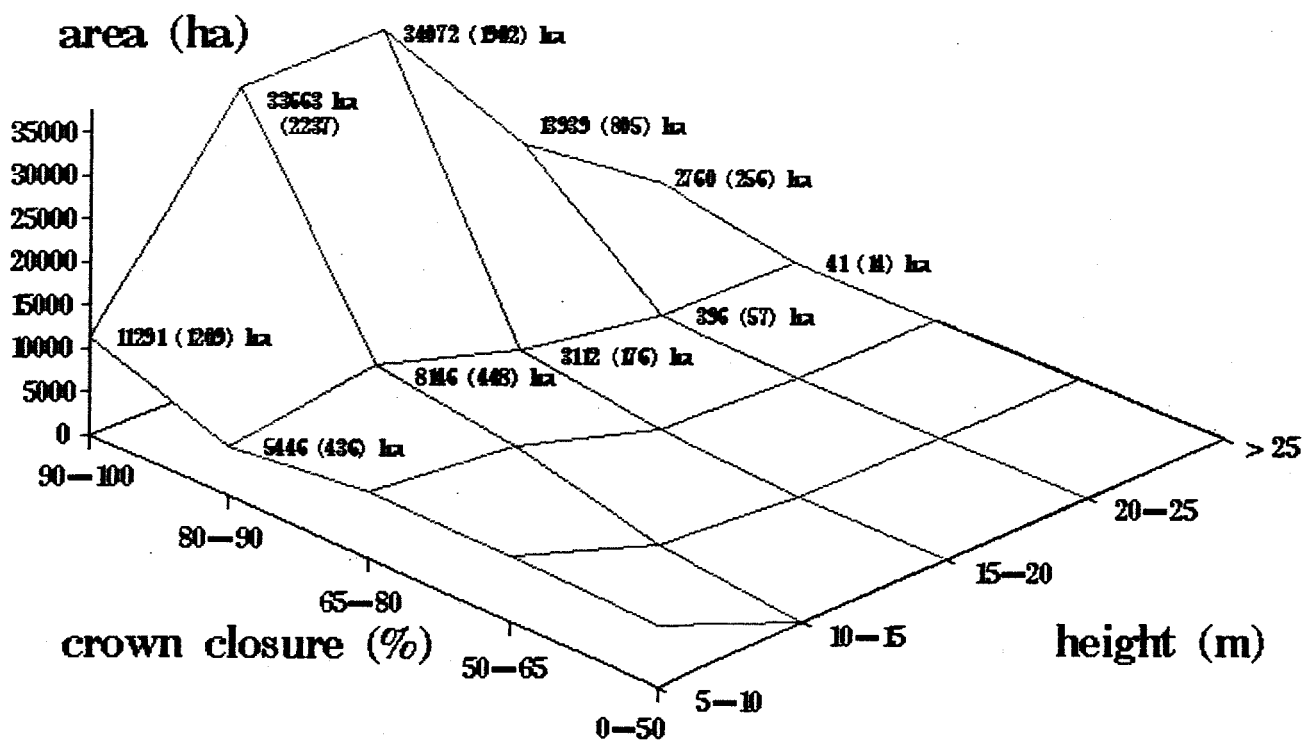


Figure 4. Area estimates in various height - canopy closure classes in (A) Newcastle County, (B) Kent County, (C) Sussex County, and (D) Delaware. The numbers next to the vertices are areal estimates for the different height-canopy closure classes, in hectares. The numbers in parentheses report one standard error, in hectares.